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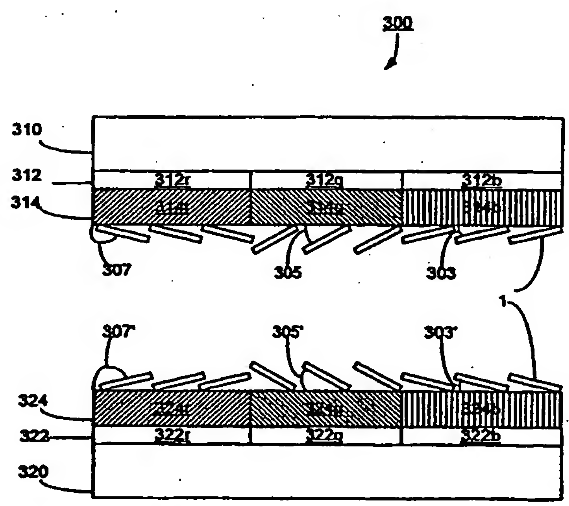
(54) Title: MULTI-DOMAIN LIQUID CRYSTAL CELL



(57) Abstract: A liquid crystal cell that includes at least one alignment layer having three domains (314), each domain having an anchoring orientation different from each other for use in a liquid crystal display. The liquid crystal cell includes first and second substrates. A first alignment layer (314) is formed on a surface of the first substrate (310). The first alignment layer has a first domain (314r) having a first anchoring orientation, a second domain having a second anchoring orientation (314g), and a third domain (314b) having a third anchoring orientation. The first, second and third anchoring orientations are different from each other. A second alignment layer (324) is formed on a surface of the second substrate (320) so as to have at least a fourth anchoring orientation. The first and second substrates are disposed parallel to each other with the first alignment layer and second alignment layer facing each other, thereby defining a cavity therebetween. Liquid crystal is in the cavity, and has three regions having different optical states associated with different colors.

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MULTI-DOMAIN LIQUID CRYSTAL CELL

This application is a continuation-in-part of our copending application Serial No. 09/213,066, filed December 16, 1998, the disclosure for which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a liquid crystal cell for a liquid crystal display and, more specifically, to a liquid crystal cell having at least one multi-domain alignment layer, which can be used in a color liquid crystal display in which different pixels are capable of exhibiting different colors.

2. Description of the Prior Art

Liquid crystals are materials that have a liquid crystal phase which exhibits flow characteristics similar to those of liquids, but, unlike liquids, have a certain amount of molecular ordering. Some of these liquid crystals also exhibit a certain amount of deformation of molecular ordering when subjected to an electric field. These liquid crystals are useful in making Liquid Crystal Displays (LCDs).

A fundamental element in a currently available LCD is a liquid crystal cell in which a liquid crystal is sandwiched between two substrates made of, for example, transparent material such as glass. A liquid crystal alignment layer is formed on each of the substrates. The liquid crystal alignment layer is a thin film covering a surface of the substrate that is subjected to an orientation making process so that the alignment layer has an anchoring orientation. Such a liquid crystal alignment layer with the anchoring orientation aligns adjacent liquid crystal molecules according to the anchoring orientation so as to form a pre-tilt angle, normally in the range of 0.5 to 15^0, from the surface of the substrate. The orientation process can be a mechanical rubbing treatment, a photo-alignment, an oblique deposition process, or other processes known in the art. The scope of the pre-tilt angle is dependent on the composition of the alignment layer as well as processing parameters such as rubbing speed, rubbing pressure, etc., when the alignment layer is processed by a mechanical rubbing treatment.

It is known in the art that the alignment of the molecules in the particular liquid crystal is very important in producing properly functioning devices utilizing liquid crystals. For example, the orientation of the liquid crystal molecule may cause an asymmetrical dependence of the viewing angle on the contrast. In other words, a liquid crystal cell may suffer from intrinsic drawbacks including change of the contrast depending upon the viewing angle and black/white inversion when used in a LCD.

Because the alignment of the liquid crystal molecules is related to the anchoring energy or anchoring orientation of the alignment layer, it has been urgently required to

develop a new method of processing an alignment layer so that the alignment layer can have proper anchoring orientation and new liquid crystal cells with a less viewing angle dependency.

SUMMARY OF THE INVENTION

The present invention provides a multi-domain liquid crystal cell that includes at least one alignment layer having a plurality of domains, each domain having an anchoring orientation different from each other, capable of aligning the liquid crystal molecules in different pre-tilt angles and thus widening the view angle. The present invention also provides methods to make such multi-domain liquid crystal cell.

In one aspect, the present invention relates to a liquid crystal cell for a liquid crystal display including first and second substrates. A first alignment layer is formed on a surface of the first substrate. The first alignment layer has a first domain having a first anchoring orientation, a second domain having a second anchoring orientation, and a third domain having a third anchoring orientation. The first, second, and third anchoring orientations are different from each other. A second alignment layer is formed on a surface of the second substrate so as to have at least a fourth anchoring orientation. The first and second substrates are disposed parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween. A liquid crystal is disposed in the cavity. The liquid crystal has at least three regions: a first region having a first optical state and a second optical state different from the first optical state, the first region displaying

a first color in the first optical state, a second region having a first optical state and a second optical state different from the first optical state, the second region displaying a second color in the first optical state, and a third region having a first optical state and a second optical state different from the first optical state, the third region displaying a third color in the first optical state. Each of the three colors is different from the other two colors, and the liquid crystal is disposed so as to have its first region located between the first domain of the first alignment layer and a first portion of the second alignment layer, its second region located between the second domain of the first alignment layer and a second portion of the second alignment layer, and its third region located between the third domain of the first alignment layer and a third portion of the second alignment layer, respectively.

The present invention also relates to a liquid crystal cell to fully take advantage of the newly discovered liquid crystal display capable of exhibiting different colors in different regions, as disclosed in the parent application, by having at least one multi-domain alignment layer so as to have a different pre-tilt angle for each domain, which can widen view angle or show rich gray scale image.

In another aspect, the liquid crystal cell for a liquid crystal display, includes first

and second substrates. A first alignment layer is formed on a surface of the first substrate. The first alignment layer includes a plurality of neighboring domains, where the total number of the domains is an integer m, m greater than two. Each domain has an anchoring orientation different from that of its neighboring domains. A second alignment layer is formed on a surface of the second substrate. The second alignment layer includes a plurality of neighboring domains, where the total number of the domains is an integer n. Each domain of the second alignment layer has an anchoring orientation different from that of its neighboring domains. The first and second substrates are disposed parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween. And a liquid crystal is disposed in the cavity. m and n can be different or same. In a particular embodiment, m and n are equal to three.

Yet another aspect of the invention is a method of constructing a liquid crystal cell for use in a liquid crystal display. A first and second substrates are coated with first and second alignment layers respectively. The first alignment layer is subjected to a first orientation making process so that the first substrate has a pixel area divided into three domains: a first domain having a first anchoring orientation, a second domain having a second anchoring orientation, and a third domain having a third anchoring orientation. The second alignment layer is subjected to a second orientation making process so that the second substrate has at least a fourth anchoring orientation. The first substrate and the second substrate are placed parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween. A liquid crystal is injected into the cavity to form the liquid crystal cell. In one embodiment of the invention, the first orientation

making process includes the step of illuminating the first domain of the first alignment layer with a linearly polarized light having a first polarization direction, so that the first domain of the first alignment layer becomes cured, so as to have the first anchoring orientation. The first orientation making process also includes the step of illuminating the second domain of the first alignment layer with a linearly polarized light having a second polarization direction, so that the second domain of the first alignment layer becomes cured, so as to have the second anchoring orientation. The first orientation making process further includes the step of illuminating the third domain of the first alignment layer with a linearly polarized light having a third polarization direction, so that the third domain of the first alignment layer becomes cured, so as to have the third anchoring orientation. The second orientation making process includes a step of rubbing the second alignment layer in a fourth direction, so as to have the fourth anchoring orientation. Alternatively, the second orientation making process includes a step of illuminating the second alignment layer with a linearly polarized light with a fourth polarization direction so that the second substrate has the fourth anchoring orientation.

Yet another aspect of the invention is a method of constructing a liquid crystal cell for use in a liquid crystal display. The method includes a step of coating first and second substrates with first and second alignment layers respectively, a step of subjecting the first alignment layer to a first orientation making process so that the first substrate has a pixel area divided into m domains, m being an integer greater than two, each domain having an anchoring orientation different from that of its neighboring domains, a step of subjecting the second alignment layer to a second orientation making process so that the second substrate

has a pixel area divided into n domains, n being an integer, each domain having an anchoring orientation different from that of its neighboring domains, a step of placing the first substrate and the second substrate parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween, and a step of injecting a liquid crystal into the cavity. Photo-alignment and mechanical rubbing technique can be used in the first and second orientation making processes.

These and other aspects of the invention will become apparent from the following description of the preferred embodiments taken in conjunction with the following drawings. As would be obvious to one skilled in the art, many variations and modifications of the invention may be effected without departing from the spirit and scope of the novel concepts of the disclosure.

BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWINGS

FIG. 1 is a side schematic view of a liquid crystal cell of a first embodiment of the invention.

FIGS. 2A and 2B are a top view of the first and second alignment layers of the liquid crystal cell shown in FIG. 1, demonstrating that the first alignment layer has three domains, each having a different anchoring orientation, as shown in FIG. 2A, and the second alignment layer has a uniform anchoring orientation, as shown in FIG. 2B.

FIG. 3 is a side schematic view of a liquid crystal cell of a second embodiment of the invention.

FIG. 4A and 4B are a top view of the first and second alignment layers of the liquid crystal cell shown in FIG. 3, demonstrating that the first alignment layer has three domains, each having a different anchoring orientation, as shown in FIG. 3A, and the second alignment layer also has three domains, each having a different anchoring orientation, as shown in FIG. 3B.

FIGS. 5A-5B are a top view of the first and second alignment layers that can be used in a liquid crystal cell according to a third embodiment of the present invention, demonstrating that the first alignment layer has multiple domains, each having a different anchoring orientation, as shown in FIG. 5A, and the second alignment layer has multiple domains, each having a different anchoring orientation, as shown in FIG. 5B.

FIGS. 6A-6F schematically show a configuration of a liquid crystal cell formed by photo-alignment according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

A preferred embodiment of the invention is now described in detail. Referring to the drawings, like numbers indicate like parts throughout the views. As used in the description

herein and throughout the claims, the following terms take the meanings explicitly associated herein, unless the context clearly dictates otherwise: the meaning of "a," "an," and "the" includes plural reference, the meaning of "in" includes "in" and "on."

As shown in FIG. 1, one embodiment of the invention is a liquid crystal cell 100. The liquid crystal cell 100 includes first and second substrates 10 and 20. A liquid crystal layer is sandwiched between the first and second substrates 10 and 20. For simplicity, the liquid crystal layer is not fully shown except several representative liquid crystal molecules 1 forming the liquid crystal layer. (It should be noted that FIG. 1 shows liquid crystal molecules 1 in the shape of rods. These are included to show only the presence of liquid crystal molecules. These rods do not represent any actual ordering, shape, or position of the liquid crystal molecules.)

An inner surface of each of the first and second substrates 10 and 20 confronting the liquid crystal layer is deposited with one of indium tin oxide (ITO) layers 12 and 22, which act as electrodes. (The ITO layer is not a continuous layer, but actually a plurality of discretely addressable electrodes.) Although ITO is used as the electrode in the embodiment disclosed herein, it is understood that the driving function could be accomplished using other transparent and conductive films, as are generally known to the art of LCD design. Furthermore, the display could employ an active matrix driver using, for example, a plurality of thin film transistors (TFT). Also, while both ITO layers 12 and 22 are transparent in this embodiment, only one electrode layer is required to be transparent if the liquid crystal cell is used in a reflective LCD.

The ITO layer 12 is covered by an alignment layer 14 while the ITO layer 22 is covered by an alignment layer 24. For the embodiment shown in FIG. 1, referring now to FIG. 2A, the alignment layer 14 includes three domains 14b, 14g, and 14r. These domains are divided by boundary lines 17, 19. Lines 17, 19 can be imaginary lines separating the domains, or lines covered by chromium or aluminum, for example. Each of the three domains 14b, 14g, and 14r has an anchoring orientation different from each other. Namely, domain 14b has an anchoring orientation 15b that defines an angle θ_1 with respect to a horizontal reference line, domain 14g has an anchoring orientation 15g that defines an angle θ_2 with respect to the horizontal reference line, and domain 14r has an anchoring orientation 15r that defines an angle θ_3 with respect to the horizontal reference line. As known to people skilled in the art, this means that the axes of all the molecules in each of these domains are substantially aligned in one direction defined by the corresponding anchoring orientation. Each of the angles can take any value in the range of 0 to 360^0. The difference between two neighboring angles, i.e., $\theta_2 - \theta_1$ or $\theta_3 - \theta_2$, can be different or same.

Referring now to FIG. 2B, the alignment layer 24 has only one anchoring orientation 25 that defines an angle θ_1' with respect to a reference line. θ_1' can take any value in the range of 0 to 360^0.

Referring now back to FIG. 1, domain 14b of the alignment layer 14 has a pre-tilt angle 3, domain 14g of the alignment layer 14 has a pre-tilt angle 5, and domain 14r of the alignment layer 14 has a pre-tilt angle 7. These pre-tilt angles are formed because liquid crystal molecules 1 tend to orient themselves with molecular orientations on surfaces to

which they are adjacent. In this embodiment, the pre-tilt angle 7 is greater than the pre-tilt angle 5 which itself is greater than the pre-tilt angle 3. Moreover, the alignment layer 24 has a uniform pre-tilt angle 3' because the alignment layer 24 has just one anchoring orientation. In the case where the alignment layer 24 is not subject to orientation during process, the axes of the liquid crystal molecules 1 adjacent to the alignment layer 24 are not aligned in a specific direction and thus there would be no pre-tilt angle for the alignment layer 24. Note that for the embodiment shown in FIG. 1, each of the ITO layers 12, 22 includes three elements so as to apply an electric field individually, or in combination to the liquid crystal.

FIG. 3 shows an alternative embodiment of FIG. 1. In FIG. 3, unlike the embodiment shown in FIG. 1 where the alignment layer 24 has a uniform anchoring orientation, alignment layer 324 has three domains 324b, 324g, and 324r. Each of the three domains 324b, 324g, and 324r has an anchoring orientation different from each other, as shown in FIG. 4B. Namely, domain 324b has an anchoring orientation 325b that defines an angle θ_1' with respect to a horizontal reference line, domain 324g has an anchoring orientation 325g that defines an angle θ_2' with respect to the horizontal reference line, and domain 324r has an anchoring orientation 325r that defines an angle θ_3' with respect to the horizontal reference line. Domains 324b, 324g and 324r are separated by lines 327 and 329. In this embodiment, as shown in FIGS. 4A and 4B, orientation angles θ_1', θ_2', and θ_3' of the alignment layer 324 are corresponding to orientation angles θ_1, θ_2, and θ_3 of the alignment layer 314, respectively. However, they are not necessarily the same value. Thus, referring again to FIG. 3, the pre-tilt angle 303 of the domain 314b of the alignment layer 314 can be different or same to the pre-tilt angle 303' of the domain 324b of the alignment layer 324. Likewise, the pre-tilt angle

305 of the domain 314g of the alignment layer 314 can be different or same to the pre-tilt angle 305' of the domain 324g of the alignment layer 324 while the pre-tilt angle 307 of the domain 314r of the alignment layer 314 can be different or same to the pre-tilt angle 307' of the domain 324r of the alignment layer 324.

In the above described embodiments, an alignment layer at most has three domains, each domain having a specific anchoring orientation. An alignment layers indeed can have a plurality of domains more than three. According to another embodiment of the present invention, a liquid crystal cell includes a first alignment layer that can have m domains, m being an integer greater than two, and a second alignment layer that can have n domains, n being an integer, where m and n can be different or the same. In this embodiment, the anchoring orientations of any two neighboring domains in the first alignment layer can be the same or different. If the difference between the anchoring orientations of any two neighboring domains in the first alignment layer is a constant in a particular embodiment, that constant can be $2\pi/m$, for example. Likewise, the anchoring orientations of any two neighboring domains in the second alignment layer can be same or different. If the difference between the anchoring orientations of any two neighboring domains in the second alignment layer is a constant in a particular embodiment, that constant can be $2\pi/n$.

FIGS. 5A and 5B show an example of this embodiment, where $m = n = 6$. In this example, the first alignment layer 514 has six domains 514a - 514f with corresponding anchoring orientations represented by angles θ_1 - θ_6. The difference between any two neighboring anchoring orientations, for example, between θ_3 and θ_2, is a constant, i.e., $\theta_3 - \theta_2$

$= \theta_2 - \theta_1 = (360^0)/6 = 60^0$. The second alignment layer 524 also has six domains 524a - 524f with corresponding anchoring orientations represented by angles θ_1' - θ_6'. The difference between any two neighboring anchoring orientations, for example, between θ_3' and θ_2', is a constant, i.e., $\theta_3' - \theta_{2'} = \theta_2' - \theta_1' = (360^0)/6 = 60^0$. In general, the first and second alignment layers do not have same number of domains as shown in the embodiment of FIG. 1. Moreover, for each alignment layer, the orientation shift for neighboring domains can be different, i.e., $\theta_3 - \theta_2 \neq \theta_2 - \theta_1$. We note that while increasing the number of domains can widen the view angle of a liquid crystal display utilizing the multi-domain liquid crystal cell, it may, on the other hand, also increase the manufacturing time and cost.

Suitable materials for the substrate 10 or 310 include glass and other transparent solids such as quartz, as are known in the art of LCD design. In some applications, an anisotropic solid could be used as well. As for the substrate 20 or 320, it can be made from the same material used to make the substrate 10 or 310, or other non-transparent materials such as silicon.

Suitable materials for alignment layers are preferably photosensitive materials that include polymers such as polyimide, polyvinyl-cinnatemate, or polyvinyl 4-methoxy-cinnamate, pre-polymers such as coumarin pre-polymer, cross-link polymers such as polyethylene, polypropylene, epoxy resins and polyvinyl acetate resins, and dye-doped polymers such as polyvinyl-alcohol with azodye.

The liquid crystal used in the present invention must be a material having a nematic liquid crystal phase that exhibits at least a first optical state exhibiting birefringence when subjected to a first electrical field (including one having a zero field strength -- a "field off state") and a second optical state, different from the first optical state, when subjected to a second electrical field, different from the first electrical field. The second optical state could include a state that exhibits little or no birefringence in the beam direction.

In particular, the liquid crystal disclosed and discussed in the parent application, which is incorporated herein in its entirety by reference, is preferably used to practice the present invention. This liquid crystal has at least three regions: a first region having a first optical state and a second optical state different from the first optical state, the first region displaying a first color in the first optical state, a second region having a first optical state and a second optical state different from the first optical state, the second region displaying a second color in the first optical state, and a third region having a first optical state and a second optical state different from the first optical state, the third region displaying a third color in the first optical state. Each of the three colors is different from the other two colors. Three colors can be red, green, and blue, or other colors such as magenta, yellow, and cyan.

In a particular embodiment, the first liquid crystal region is a red liquid crystal region, the second liquid crystal region is a green liquid crystal region, and the third liquid crystal region is a blue liquid crystal region. The red liquid crystal region has a different twist orientation than that of green liquid crystal region and blue liquid crystal region. Similarly, the green liquid crystal region has a different twist orientation than that of red liquid crystal

region and blue liquid crystal region. Likewise, the blue liquid crystal region has a different twist orientation than that of red liquid crystal region and green liquid crystal region. In this embodiment, the liquid crystal is of the XSTN type, has an optical thickness l of, *e.g.*, 860 nm and has a geometric thickness d over intrinsic pitch p (resulting from chiral doping) of, *e.g.*, $d/p = 0.48$. The optical thickness l of a material is defined as: $l = \Delta n \cdot d$, where d is the geometrical thickness of the material and Δn is the double refraction of the material. By having different twist orientations, the liquid crystal in the different regions have different axes of birefringence while in the field off state.

To use the liquid crystal in the present invention, taking the embodiment shown in FIG. 3 as an example, it is disposed so as to have its first or red region located between the domain 314r of the first alignment layer 314 and the corresponding domain 324r of the second alignment layer 324, its second or green region located between the domain 314g of the first alignment layer 314 and the corresponding domain 324g of the second alignment layer 324, and its third or blue region located between the domain 314b of the first alignment layer 314 and the corresponding domain 324b of the second alignment layer 324, respectively. Because liquid crystal molecules in each liquid crystal region have respective pre-tilt angles due to the multi-domain structure of the alignment layers 314 and 324, the scope of the viewing angle can be improved.

The liquid crystal used in the present invention also includes a chiral dopant with a concentration that makes d/p ratio normally in the range of about 0.1% and about 1.0%, where d is the cell thickness and p is the helical pitch. The chiral dopant could comprise

S811 or CB15 (among others), both are preferred to practice the present invention. If S811 is used, the concentration is about 0.1% when using a TN or SbTN embodiment and about 0.5% when using an STN or XSTN embodiment. If CB15 is used, the concentration may be about 1.0% when using an STN or XSTN embodiment. For other chiral dopants that have different helical twist power and could be used to practice the present invention, the concentration may be different and beyond the range of about 0.1 % and about 1.0 %.

A method of making the liquid crystal cell according to the embodiments of the present invention now is given with particular reference to FIG. 6.

First, an alignment layer 614 is coated on a top substrate 610 so as to overlay an ITO layer 612 (not shown) over the entire surface. The coating can be done by either spin coating (e.g., at 3000rpm for 60 seconds) or by printing, or other approaches used in the art, followed by baking at temperatures up to about 100-250 C° for a few hours. The alignment layer 614 is made from a photo-alignable compound or a photosensitive medium. Such a compound could include a pre-polymer, a polymer, a cross-linkable polymer, a dye-doped polymer, or a combination of them. This forms an orientation surface 602 having domains 614b, 614g, and 614r. A first mask 611b is placed over the orientation surface 602 so as to cover the domains 614g and 614r.

Next, the domain 614b is illuminated with a linearly polarized light 650 having a first polar orientation 652. In one embodiment, the light could be ultra-violet in the range of 300 nm to 360 nm, however other wavelengths of light could also be employed. The first polar

orientation 652 is parallel (or could be perpendicular) to the anchoring orientation of the domain 614b. The photo-alignable compound of the domain 614b of the first alignment layer 614 becomes cured so as to have a first orientation 615b, as shown in FIG. 6B. If the photo-alignable compound is a cross linkable polymer, then the curing process occurs when the molecules of the polymer become cross-linked.

Next, as shown in FIG. 6C, a second mask 611g is placed over the orientation surface 602 so as to cover the domains 614b and 614r.

The domain 614g of the alignment layer 614 is then illuminated with a linearly polarized light 654 having a second polar orientation 656, corresponding to the anchoring orientation of the domain 614g. The illumination continues until the photo-alignable compound of the alignment layer 614 subtending the domain 614g becomes cured so as to have a second molecular orientation 615g, as shown in FIG. 6D.

Next, as shown in FIG. 6E, a third mask 611r is placed over the orientation surface 602 so as to cover the domains 614b and 614g.

The domain 614r of the alignment layer 614 is then illuminated with a linearly polarized light 658 having a second polar orientation 660, corresponding to the anchoring orientation of the domain 614r. The illumination continues until the photo-alignable compound of the alignment layer 614 subtending the domain 614r becomes cured so as to have a third molecular orientation 615r, as shown in FIG. 6F. As shown in FIG. 6F, this

results in the alignment layer 614 having three domains 614b, 614g, and 614r with three anchoring orientations 615b, 615g, and 615r, respectively.

Some photo-alignable materials allow themselves to be "written over" so that their molecules will first align themselves with a first light and subsequently align themselves with a second light. Using one of these types of materials, it would be possible to do away with one of the masks recited above. For example, the first step would involve illuminating the entire orientation surface with a first linearly polarized light and then following the steps shown in FIGS. 6C-6F.

In the process disclosed above, the photo-curable polymer could be a photo polymer available from Elsicon, Inc., Quillen Building, Suite 1C1, 3521 Silverside Road, Wilmington, DE 19810. The masks would be similar to the type of masks used in semiconductor photolithography (although this embodiment would not require the same level of precision as that required in manufacturing integrated circuits). The ITO layers could be applied using one of several methods commonly used in LCD technology.

A similar process can be repeated to provide a bottom substrate that has an alignment layer having three domains, each having an anchoring orientation, or has only one anchoring orientation (in this case, no mask would be needed). Or alternatively, a mechanical rubbing process can be used to provide a bottom substrate that has an alignment layer which has at least one anchoring orientation. The mechanical rubbing process is known in the art.

The top substrate and the bottom substrate can then be assembled together with the alignment layers facing to each other, thereby defining a cavity therebetween. A liquid crystal is injected into the cavity thus to form a liquid crystal cell. Other technologies known in the art such as vacuum deposition or sputtering silicon oxide, can also be used to process the alignment layers. If a first alignment layer is processed by rubbing and a second alignment layer is processed by photo-alignment or other process or a combination of them, the formed liquid crystal cell can be called a hybrid liquid crystal cell. In general, according to the present invention, a hybrid liquid crystal cell relates to a liquid crystal cell that has a first alignment layer processed by a first orientation making process that includes mechanical rubbing and a second alignment layer processed a second orientation making process that is different from the first orientation making process and includes photo-alignment.

While the above process is described to make a liquid crystal cell that has three domains, it can be used to form a liquid crystal cell having other numbers of domains as well. In particular, it can be used to form a liquid crystal cell that has a top substrate with an alignment layer having n domains, and a bottom substrate with an alignment layer having m domains, where n is an integer greater than two and m is an integer.

It is important to note that the above-described figures of the drawings disclosed herein are not drawn to scale. Certain features are exaggerated to aid in explaining the invention.

The above described embodiments are given as illustrative examples only. It will be readily appreciated that many deviations may be made from the specific embodiments disclosed in this specification without departing from the invention. Accordingly, the scope of the invention is to be determined by the claims below rather than being limited to the specifically described embodiments above.

CLAIMS

What is claimed is:

1. A liquid crystal cell for a liquid crystal display, comprising:
   a. first and second substrates;
   b. a first alignment layer formed on a surface of the first substrate, the first alignment layer comprising:
      i. a first domain having a first anchoring orientation;
      ii. a second domain having a second anchoring orientation; and
      iii. a third domain having a third anchoring orientation,

      wherein the first, second, and third anchoring orientations are different from each other;
   c. a second alignment layer formed on a surface of the second substrate so as to have at least a fourth anchoring orientation, the first and second substrates disposed parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween; and
   d. a liquid crystal disposed in the cavity.

2. The liquid crystal cell of Claim 1, wherein the liquid crystal having at least three regions, comprises:

a. a first region having a first optical state and a second optical state different from the first optical state, the first region displaying a first color in the first optical state;

b. a second region having a first optical state and a second optical state different from the first optical state, the second region displaying a second color in the first optical state; and

c. a third region having a first optical state and a second optical state different from the first optical state, the third region displaying a third color in the first optical state;

wherein each of the three colors is different from the other two colors, and the liquid crystal is disposed so as to have its first region located between the first domain of the first alignment layer and a first portion of the second alignment layer, its second region located between the second domain of the first alignment layer and a second portion of the second alignment layer, its third region located between the third domain of the first alignment layer and a third portion of the second alignment layer, respectively.

3. The liquid crystal cell of Claim 2, wherein the liquid crystal material comprises an XSTN liquid crystal.

4. The liquid crystal cell of Claim 3, wherein the XSTN liquid crystal has a twist angle between 90° and 270°.

5. The liquid crystal cell of Claim 2, wherein the liquid crystal material comprises an SbTN liquid crystal having a twist angle between 0° and 90°.

6. The liquid crystal cell of Claim 2, further comprising a plurality of field-applying elements, each for selectively applying an electric field to each of the first region, the second region and the third region of the liquid crystal.

7. The liquid crystal cell of Claim 6, wherein each of the plurality of field-applying elements comprises an electrode.

8. The liquid crystal cell of Claim 7, wherein the electrode comprises ITO.

9. The liquid crystal cell of Claim 2, wherein the first color is red, the second color is green, and the third color is blue.

10. The liquid crystal cell of Claim 3, wherein the first color is magenta, the second color is yellow, and the third color is cyan.

11. The liquid crystal cell of Claim 1, wherein at least one of the first and second substrates is transparent.

12. The liquid crystal cell of Claim 1, wherein the first and second alignment layers are made of polyimide.

13. The liquid crystal cell of Claim 1, wherein at least one of the first and second alignment layers is made of a photosensitive medium.

14. The liquid crystal cell of Claim 13, wherein the photosensitive medium is a material selected from a group of consisting of a polymer including polyimide, polyvinyl-cinnatemate and polyvinyl 4-methoxy-cinnamate, a pre-polymer including coumarin pre-polymer, a cross-linkable polymer including polyethylene, polypropylene, epoxy resins and polyvinyl acetate resins, or dye-doped polymer including polyvinyl-alcohol with azodye.

15. A liquid crystal cell for a liquid crystal display, comprising:

a. first and second substrates;

b. a first alignment layer formed on a surface of the first substrate, the first alignment layer comprising a plurality of neighboring domains, the total number of the domains being an integer m, m greater than two, each domain having a anchoring orientation different from that of its neighboring domains;

c. a second alignment layer formed on a surface of the second substrate, the second alignment layer comprising a plurality of neighboring domains, the total number of the domains being an integer n, each domain having a anchoring orientation different from that of its neighboring domains, the first and second substrates disposed parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween; and

d. a liquid crystal disposed in the cavity.

16. The liquid crystal cell of Claim 15, wherein at least one of the first and second substrates is transparent.

17. The liquid crystal cell of Claim 15, wherein the difference between the anchoring orientation of domain i and the anchoring orientation of domain i-1 of the first alignment layer is different from the difference between the anchoring orientation of domain i and the anchoring orientation of domain i+1 of the first alignment layer, i being an integer in the range of 2 to m-1.

18. The liquid crystal cell of Claim 15, wherein the difference between the anchoring orientation of domain j and the anchoring orientation of domain j-1 of the second alignment layer is different from the difference between the anchoring orientation of domain j and the anchoring orientation of domain j+1 of the second alignment layer, j being an integer in the range of 2 to n-1.

19. The liquid crystal cell of Claim 15, wherein the difference between the anchoring orientations of any two neighboring domains of the first alignment layer is a constant.

20. The liquid crystal cell of Claim 19, wherein the constant is ($2\pi/m$).

21. The liquid crystal cell of Claim 15, wherein the difference between the anchoring orientations of any two neighboring domains of the second alignment layer is a constant.

22. The liquid crystal cell of Claim 21, wherein the constant is $(2\pi/n)$.

23. The liquid crystal cell of Claim 15, wherein m is not equal to n.

24. The liquid crystal cell of Claim 15, wherein m is equal to n.

25. The liquid crystal cell of Claim 24, wherein the liquid crystal has n regions and is disposed so that there is one region of the liquid crystal located between one domain of the first alignment layer and a corresponding domain of the second alignment layer.

26. The liquid crystal cell of Claim 15, wherein the liquid crystal comprises a material having a nematic liquid crystal phase that exhibits at least a first optical state exhibiting birefringence when subjected to a first electrical field and a second optical state, different from the first optical state, when subjected to a second electrical field, different from the first electrical field, and a chiral dopant with a concentration that makes d/p ratio in the range of about 0.1% and about 1.0%, d being the cell geometrical thickness and p being the helical pitch.

27. The liquid crystal cell of Claim 26, wherein the strength of the first and second electrical fields comprises a zero field strength.

28. The liquid crystal cell of Claim 26, wherein the second optical state comprises a state that exhibits no or little birefringence.

29. A TN liquid crystal cell made according to Claim 26.

30. An STN liquid crystal cell made according to Claim 26.

31. An SbTN liquid crystal cell made according to Claim 26.

32. An XSTN liquid crystal cell made according to Claim 26.

33. A method of constructing a liquid crystal cell for use in a liquid crystal display, comprising the steps of:

a. coating first and second substrates with first and second alignment layers respectively;

b. subjecting the first alignment layer to a first orientation making process so that the first substrate has a pixel area divided into three domains: a first domain having a first anchoring orientation, a second domain having a second anchoring orientation, and a third domain having a third anchoring orientation;

c. subjecting the second alignment layer to a second orientation making process so that the second substrate has at least a fourth anchoring orientation;

d. placing the first substrate and the second substrate parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween; and

e. injecting a liquid crystal into the cavity.

34. The method of Claim 33, wherein the first orientation making process comprises the following steps:

i. illuminating the first domain of the first alignment layer with a linearly polarized light having a first polarization direction, so that the first domain of the first alignment layer becomes cured, so as to have the first anchoring orientation;

ii. illuminating the second domain of the first alignment layer with a linearly polarized light having a second polarization direction, so that the second domain of the first alignment layer becomes cured, so as to have the second anchoring orientation; and

iii. illuminating the third domain of the first alignment layer with a linearly polarized light having a third polarization direction, so that the third domain of the first alignment layer becomes cured, so as to have the third anchoring orientation.

35. The method of Claim 34, wherein the step of illuminating the first domain comprises a step of placing a first mask over the first alignment layer so as to cover the second and third domains during illuminating.

36. The method of Claim 34, wherein the step of illuminating the second domain comprises a step of placing a second mask over the first alignment layer so as to cover the first and third domains during illuminating.

37. The method of Claim 34, wherein the step of illuminating the third domain comprises a step of placing a third mask over the first alignment layer so as to cover the first and second domains during illuminating.

38. The method of Claim 34, wherein the first alignment layer is made of a photo-alignable material.

39. The method of Claim 38, wherein the photo-alignable material comprises a pre-polymer.

40. The method of Claim 38, wherein the photo-alignable material comprises a polymer capable of being cross-linked.

41. The method of Claim 33, wherein the second orientation making process comprises a step of rubbing the second alignment layer in a fourth direction, so as to have the fourth anchoring orientation.

42. The method of Claim 33, wherein the liquid crystal having at least three regions, comprises:

a. a first region having a first optical state and a second optical state different from the first optical state, the first region displaying a first color in the first optical state;

b. a second region having a first optical state and a second optical state different from the first optical state, the second region displaying a second color in the first optical state; and

c. a third region having a first optical state and a second optical state different from the first optical state, the third region displaying a third color in the first optical state;

wherein each of the three colors is different from the other two colors.

43. The method of Claim 42, wherein the injecting step further comprises the step of disposing the liquid crystal so as to have its first region located between the first domain of the first alignment layer and a first portion of the second alignment layer, its second region located between the second domain of the first alignment layer and a second portion of the second alignment layer, its third region located between the

third domain of the first alignment layer and a third portion of the second alignment layer, respectively.

44. A method of constructing a liquid crystal cell for use in a liquid crystal display, comprising the steps of:

a. coating first and second substrates with first and second alignment layers respectively;

b. subjecting the first alignment layer to a first orientation making process so that the first substrate has a pixel area divided into m domains, m being an integer greater than two, each domain having an anchoring orientation different from that of its neighboring domains;

c. subjecting the second alignment layer to a second orientation making process so that the second substrate has a pixel area divided into n domains, n being an integer, each domain having an anchoring orientation different from that of its neighboring domains;

d. placing the first substrate and the second substrate parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween; and

e. injecting a liquid crystal into the cavity.

45. The method of Claim 44, wherein the first orientation making process comprises the following steps:

i. illuminating a selected domain i, i being an integer in the range of 3 to m, of the first alignment layer with a linearly polarized light having a specific polarization direction, so that the domain i of the first alignment layer becomes cured, so as to have an i^{th} anchoring orientation that is different from that of the neighboring domains; and

ii. repeating step (i) for each domain of the first alignment layer.

46. The method of claim 45, wherein the step of illuminating a selected domain i comprises a step of placing a selected mask over the first alignment layer so as to cover domains other than the selected domain i during illuminating.

47. The method of Claim 45, wherein the difference between the anchoring orientations of any two neighboring domains is a constant.

48. The method of Claim 47, wherein the constant is ($2\pi/m$).

49. The method of Claim 44, wherein the second orientation making process comprises the following steps:

i. illuminating a selected domain j, j being an integer in the range of 1 to n, of the second alignment layer with a linearly polarized light having a specific polarization direction, so that the domain j of the second alignment layer becomes cured, so as to have an j^{th} anchoring orientation that is different from that of the neighboring domains; and

ii. repeating step (i) for each domain of the second alignment layer.

50. The method of Claim 49, wherein the step of illuminating a selected domain j comprises a step of placing a selected mask over the second alignment layer so as to cover domains other than the selected domain j during illuminating.

51. The method of Claim 49, wherein the difference between the anchoring orientations of any two neighboring domains is a constant.

52. The method of Claim 51, wherein the constant is $(2\pi/m)$.

53. The method of Claim 44, wherein m is not equal to n.

54. The method of Claim 44, wherein m is equal to n.

55. The method of Claim 54, wherein the liquid crystal has n regions and the step of injecting further comprises the step of disposing the liquid crystal so as to have one of n regions of the liquid crystal located between one domain of the first alignment layer and a corresponding domain of the second alignment layer.

56. The method of Claim 55, wherein n is equal to three.

57. The method of Claim 44, wherein the second orientation making process comprises the following steps:

    i. rubbing a selected domain j, j being an integer in the range of 1 to n, of the second alignment layer in a specific polarization direction, so that the domain j of the second alignment layer has an j^{th} anchoring orientation that is different from that of the neighboring domains; and

    ii. repeating step (i) for each domain of the second alignment layer.

58. The method of Claim 57, wherein the difference between the anchoring orientations of any two neighboring domains is a constant.

59. The method of Claim 58, wherein the constant is ($2\pi/m$).

60. The method of Claim 57, wherein m is not equal to n.

61. The method of Claim 60, wherein m is equal to three and n is equal to one.

62. The method of Claim 57, wherein m is equal to n.

63. The method of Claim 62, wherein the liquid crystal has n regions and the step of injecting further comprises the step of disposing the liquid crystal so as to have one region of the liquid crystal located between one domain of the first alignment layer and a corresponding domain of the second alignment layer.

64. A method of constructing a liquid crystal cell for use in a liquid crystal display, comprising the steps of:

a. coating first and second substrates with first and second alignment layers respectively;

b. rubbing the first alignment layer in a specific direction so that the first alignment layer has a first anchoring orientation;

c. illuminating the second alignment layer with a linearly polarized light having a first polarization direction so that the second alignment layer has a second anchoring orientation;

d. placing the first substrate and the second substrate parallel to each other with the first alignment layer and the second alignment layer facing each other, thereby defining a cavity therebetween; and

e. injecting a liquid crystal in the cavity.

65. The method of Claim 64, further comprising the following steps:

a. illuminating the second alignment layer with a linearly polarized light having a second polarization direction so that the second alignment layer has a third anchoring orientation; and

b. illuminating the second alignment with a linearly polarized light having a third polarization direction so that the second alignment layer has a fourth anchoring orientation.

66. The method of Claim 65, wherein the liquid crystal having at least three regions, comprises:

a. a first region having a first optical state and a second optical state different from the first optical state, the first region displaying a first color in the first optical state;

b. a second region having a first optical state and a second optical state different from the first optical state, the second region displaying a second color in the first optical state; and

c. a third region having a first optical state and a second optical state different from the first optical state, the third region displaying a third color in the first optical state;

wherein each of the three colors is different from the other two colors.

67. The method of Claim 66, wherein the injecting step further comprises the step of disposing the liquid crystal so as to have its first region located between the first alignment layer and a first portion of the second alignment layer that has the second anchoring orientation, its second region located between the first alignment layer and a second portion of the second alignment layer that has the third anchoring orientation, and its third region located between the first alignment layer and a third portion of the second alignment layer that has the fourth anchoring orientation, respectively.

68. A liquid crystal cell made according to Claim 64.

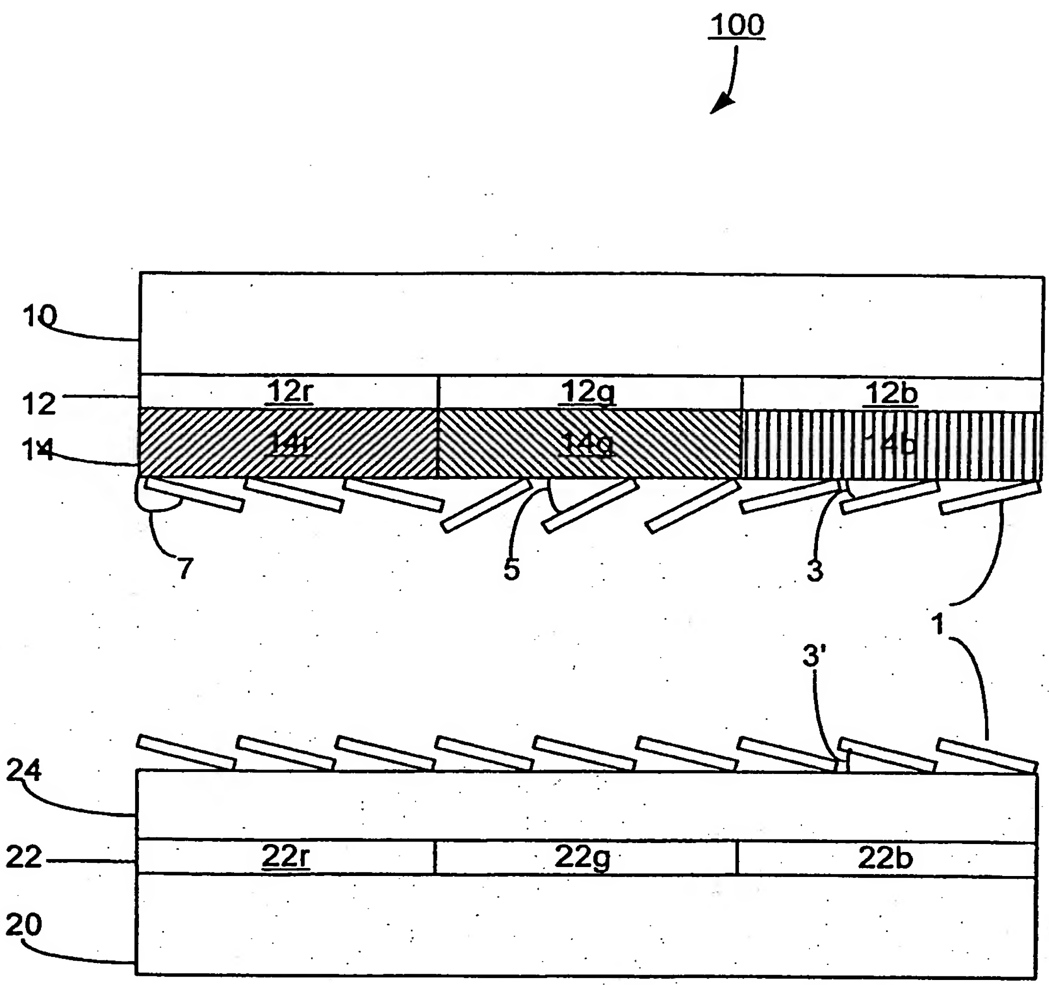


FIG. 1

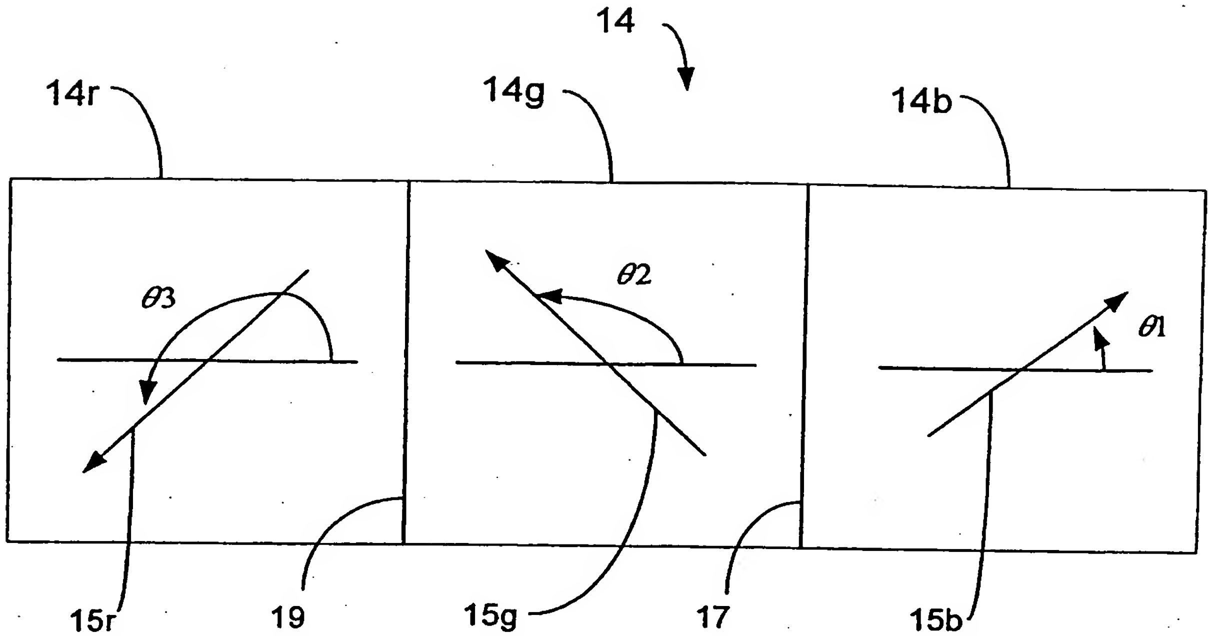


FIG. 2A

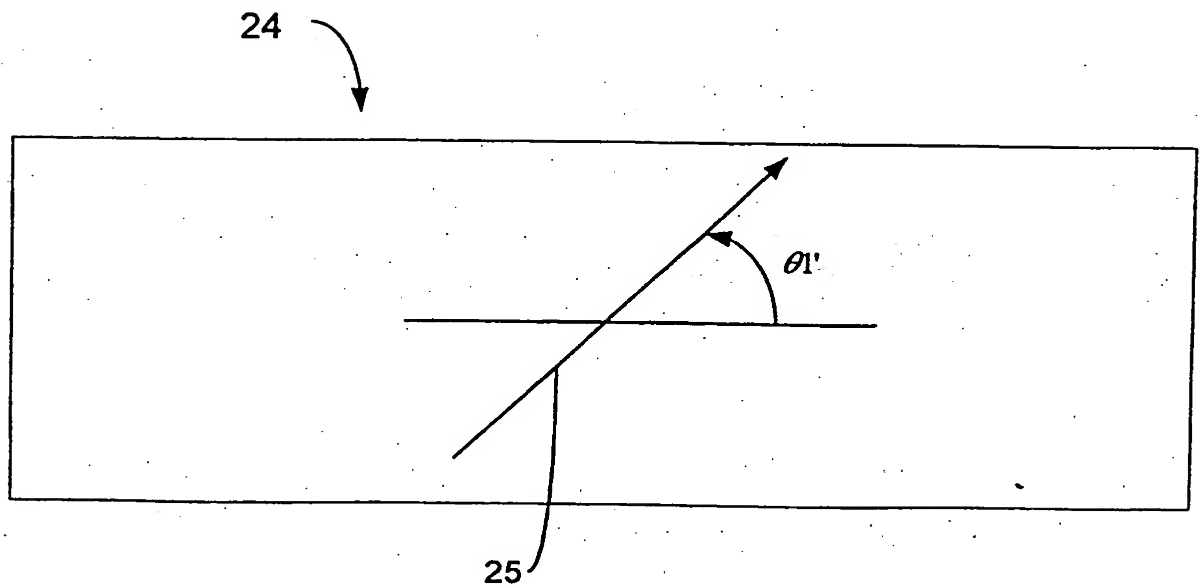
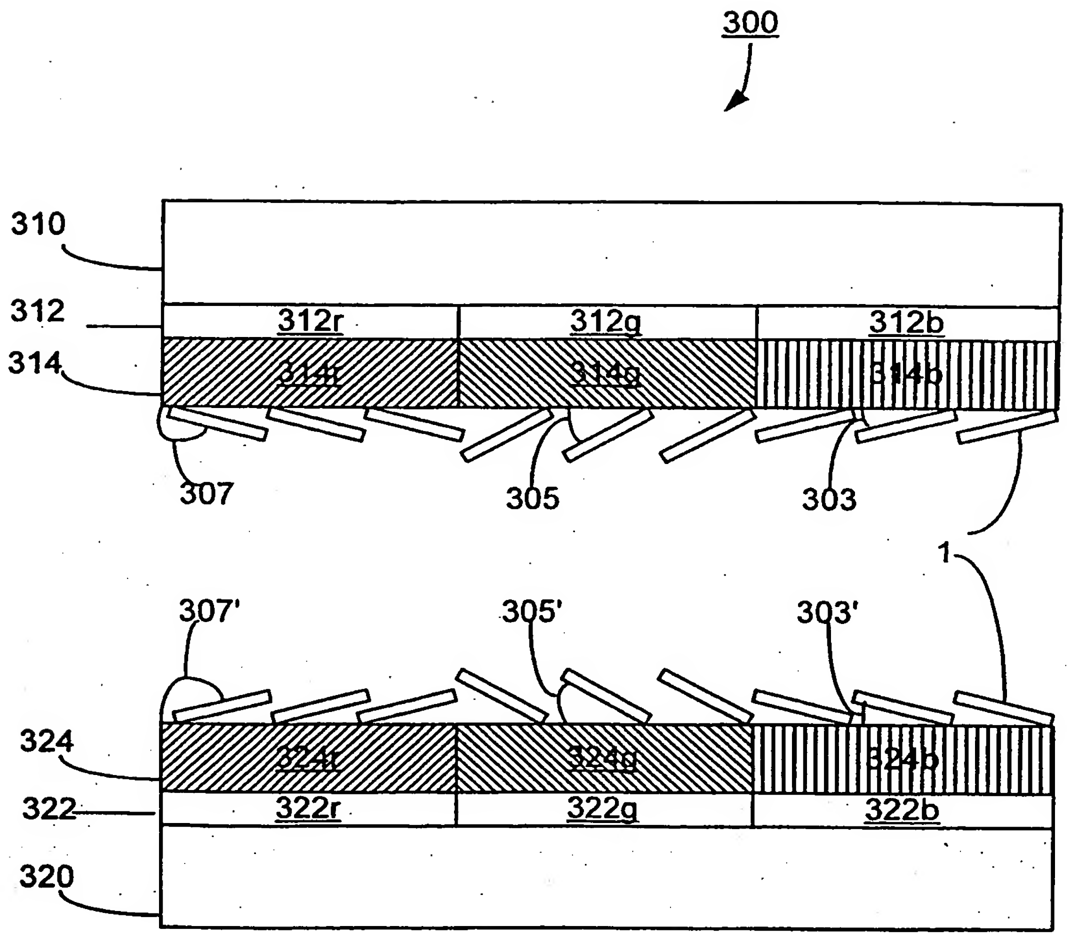


FIG. 2B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312
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312g
312b
314
314r
314g
314b
307
305
303
1
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305'
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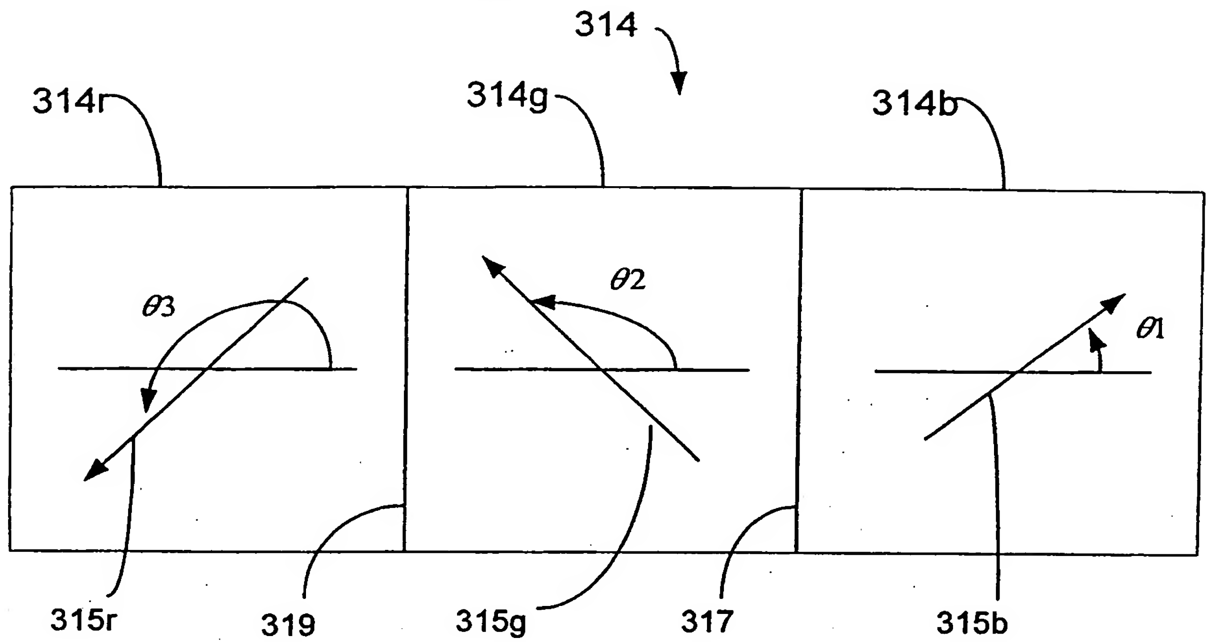
324r
324g
324b
322
322r
322g
322b
320

FIG. 3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314r
314g
314b
θ3
θ2
θ1
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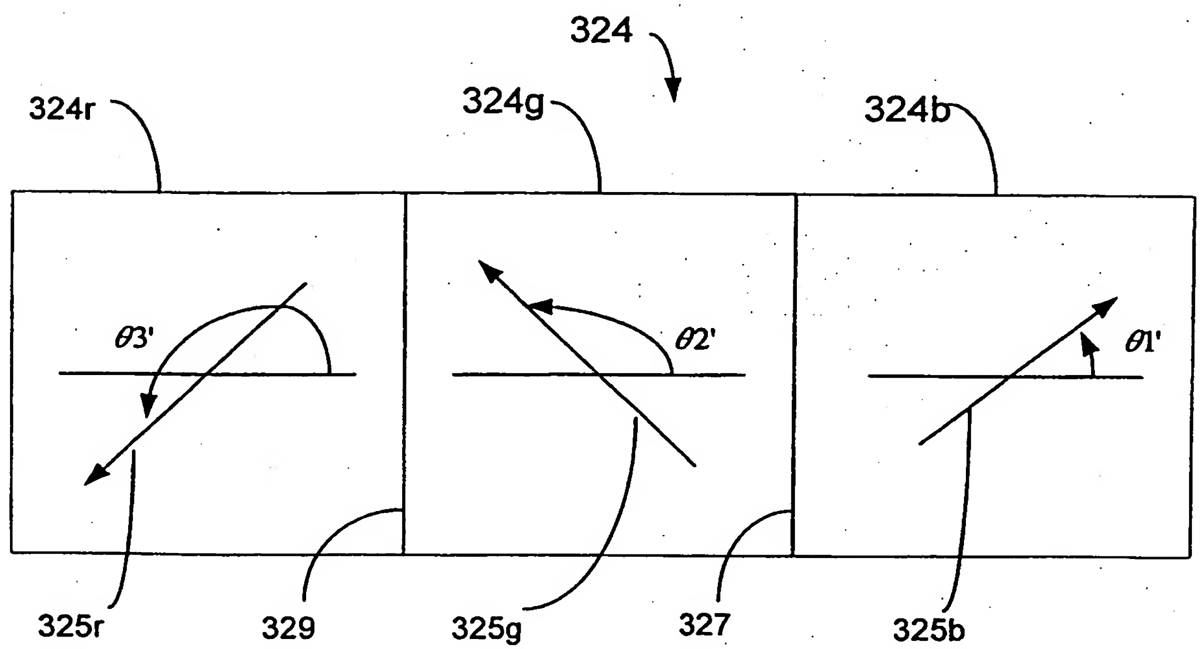
319
315g
317
315b

FIG. 4A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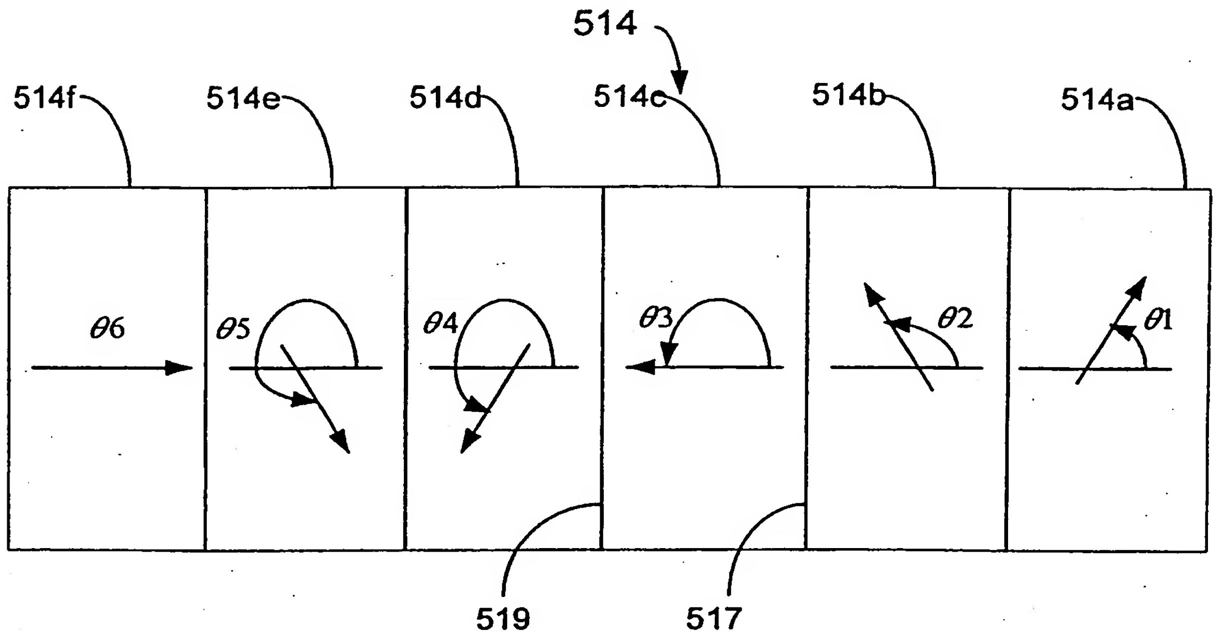
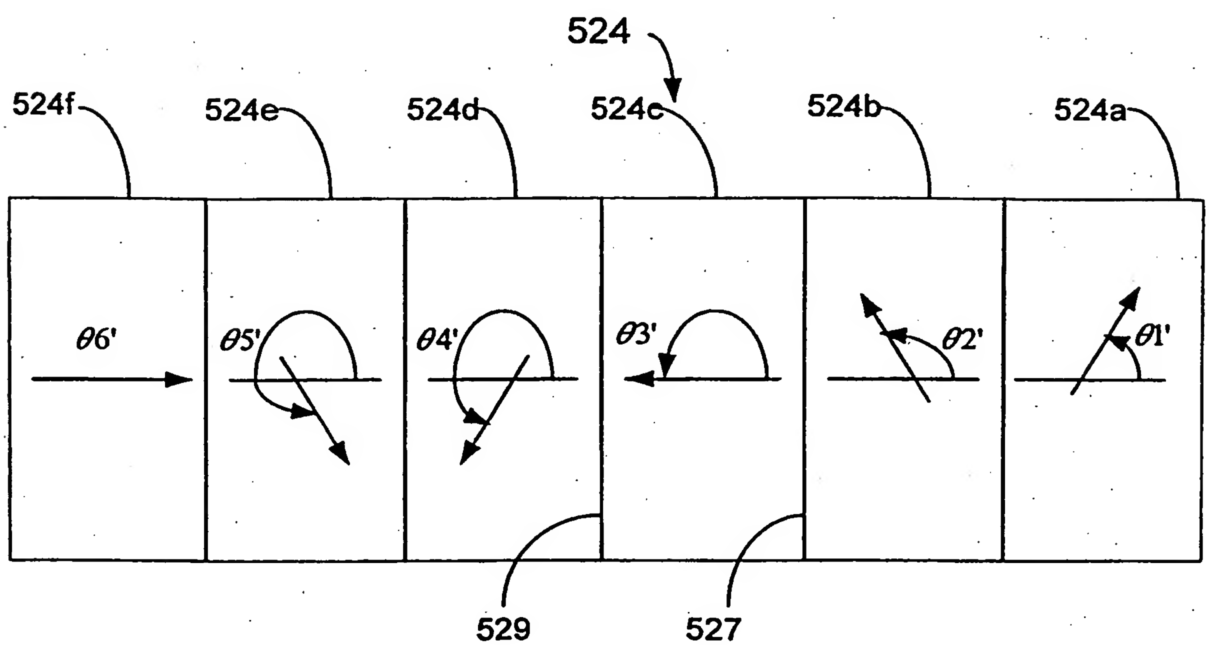
324r
324g
324b
θ3'
θ2'
θ1'
325r
329
325g
327
325b

FIG. 4B



514
514f
514e
514d
514c
514b
514a
θ6
θ5
θ4
θ3
θ2
θ1
519
517

FIG. 5A



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θ5'
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θ1'
529
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FIG. 5B

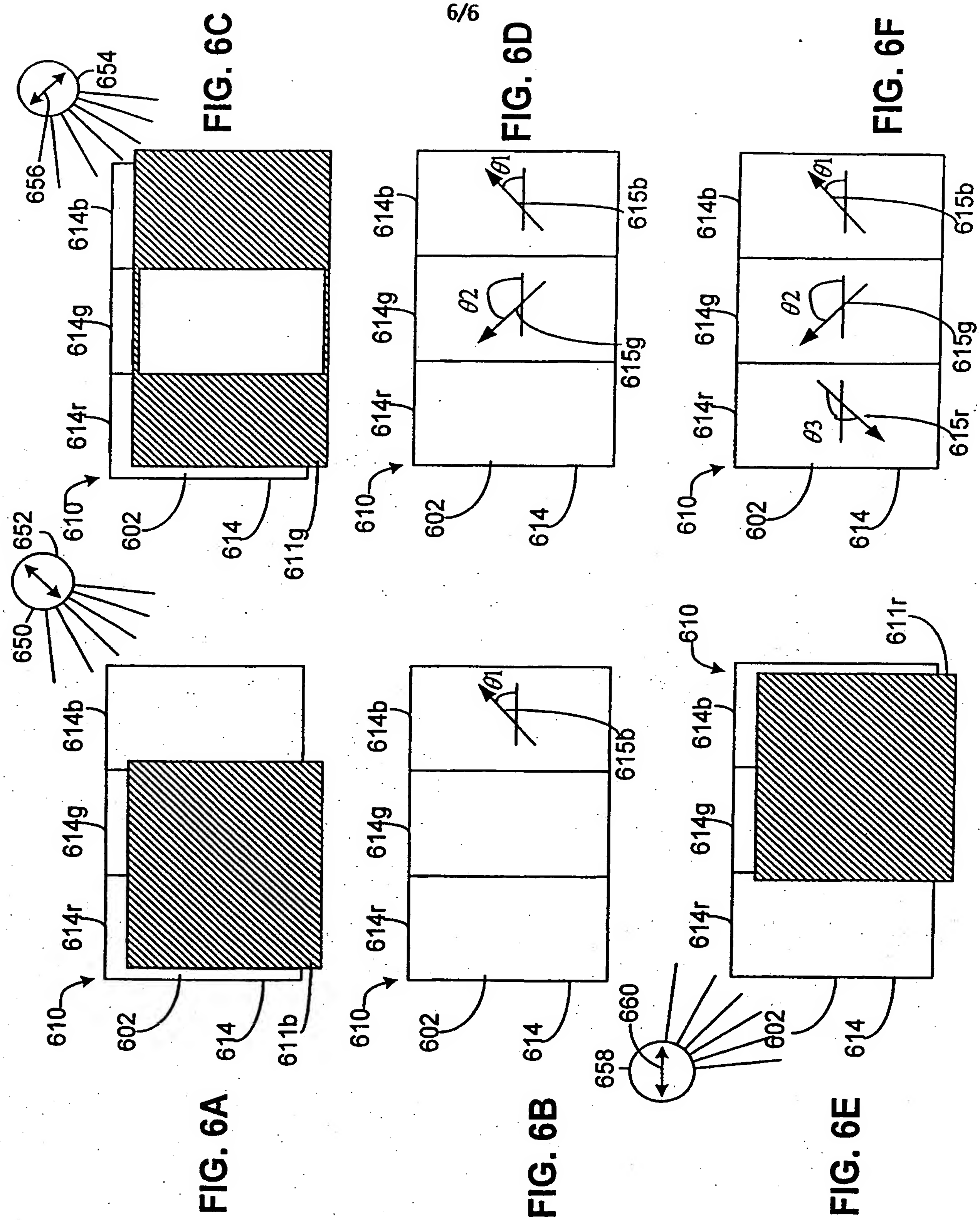

FIG. 6A

FIG. 6B

FIG. 6C

FIG. 6D

FIG. 6E

FIG. 6F

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/26153

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : G02F/133
US CL : 349/129, 123
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
U.S. : 349/129, 123

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, E	US 6,141,074 A [Bos et al) 10 October 2000 (10.10.2000), the whole document.	1,4-8,11-41 , 43-65
X	US 5,909,265 A (Kim et al) 01 June 1999 (01.06.1999), the whole document.	1,5-8, 11-29, 33-41,43-63
A	US 5,982,464 A (Wang et al) 09 November 1999 (09.11.1999), the whole document.	1-68

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search
23 NOVEMBER 2000

Date of mailing of the international search report
09 JAN 2001

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